

Flexible Organic Semiconductors for the Nuclear Industry and maybe Particle Physics?

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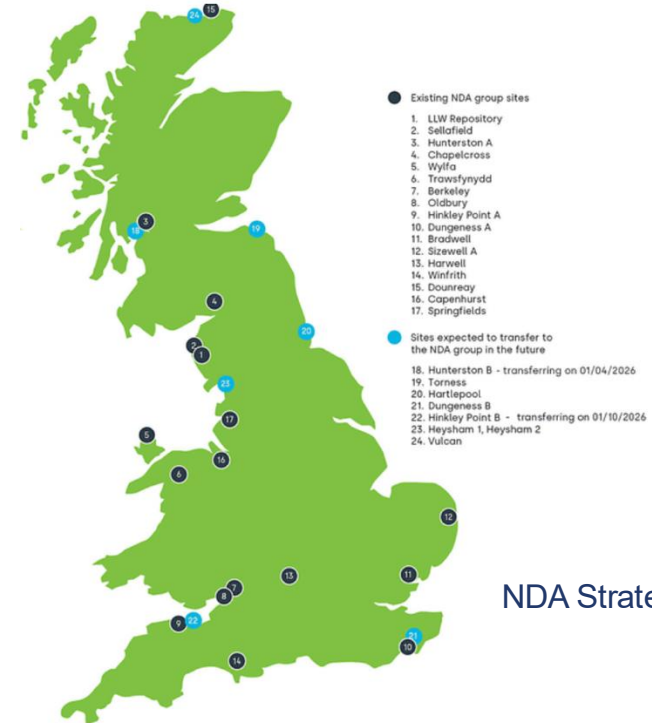


United Kingdom
National Nuclear
Laboratory

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Intro to Nuclear Decommissioning

- The Strategic Themes
 - **Site Decommissioning and Remediation**
 - Spent Fuel
 - Nuclear Materials
 - Integrated Waste Management
- **Critical Enablers**
 - R&D and more.



NDA Strategy 2026

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The Challenges

- 17 Legacy nuclear sites
- Approximately 700km of pipeline
- Mixed hazard
- Curved geometry
- Limited or impractical access
- In-situ characterisation preferred



1. Miller *et al.* Pipeline Characterisation and Decommissioning within the Nuclear Industry: Technology Review and Site Experience, NDA Publishing, 2016.

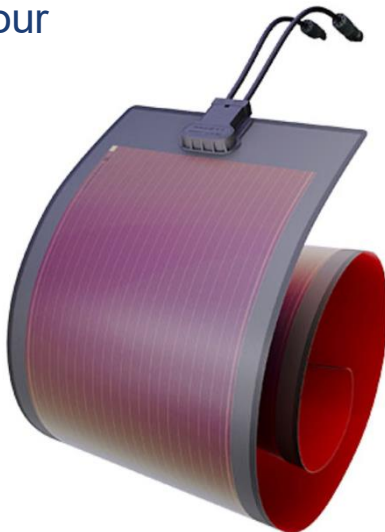
Let's Talk Technology

- Organic Semiconductors
 - Any carbon-based small molecule, oligomer, or polymer that exhibits semiconducting behaviour

Let's Talk Technology

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Curved organic photovoltaic, reproduced from heliatek.com



iPhones have been using OLED (organic LED) displays for the last 10 years.

Reproduced from apple.com

iPhone 16

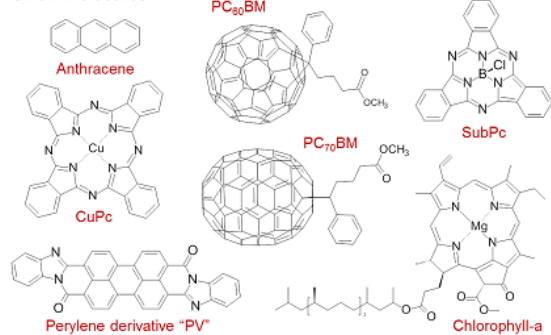
Super Retina XDR display

6.1-inch (diagonal) all-screen OLED display

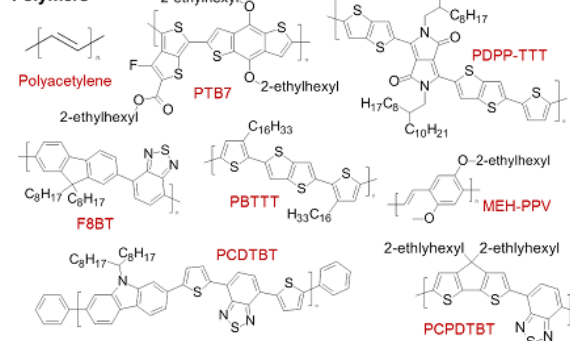
2556x1179-pixel resolution at 460 ppi

Let's Talk Chemistry/Physics

Small-molecules



Polymers



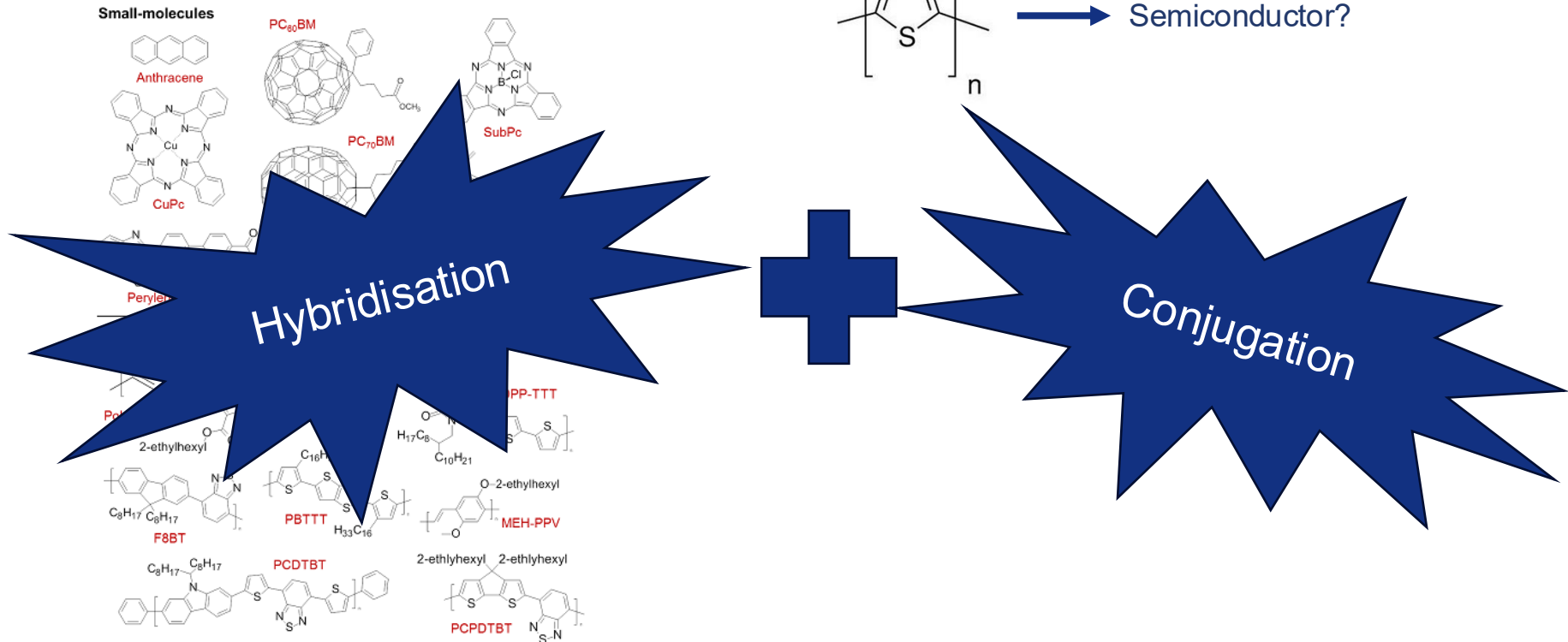
- That doesn't look like a semiconductor?
- How?
- Why?

Two magic words.



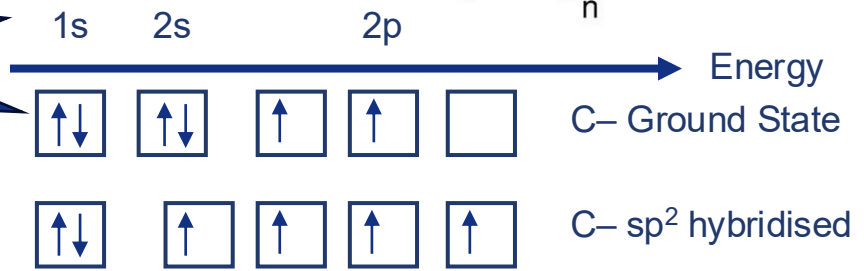
Graphic: Cavendish Laboratory, Research, Optoelectronics, Organic Semiconductors.

Magic Words

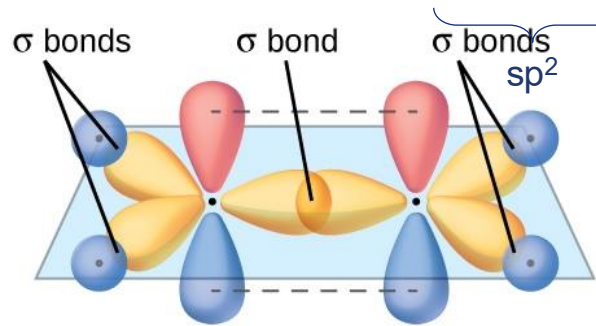
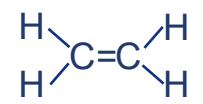


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Let's Talk Chemistry/Physics



Ethene



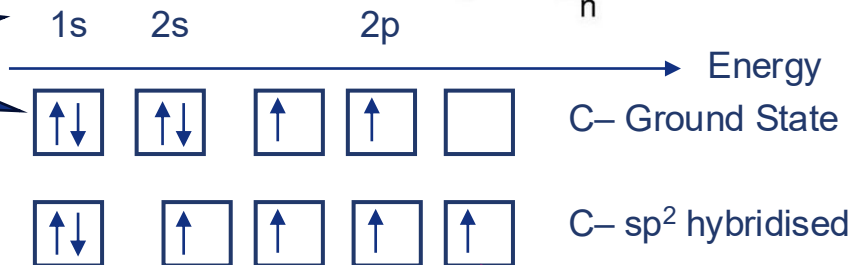
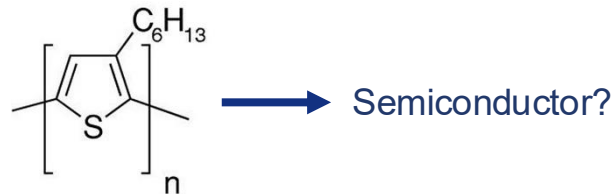
These hybridised states form these σ bonds allowing for the remaining p orbital to form a π bond with a neighbouring carbon atom.

(a)

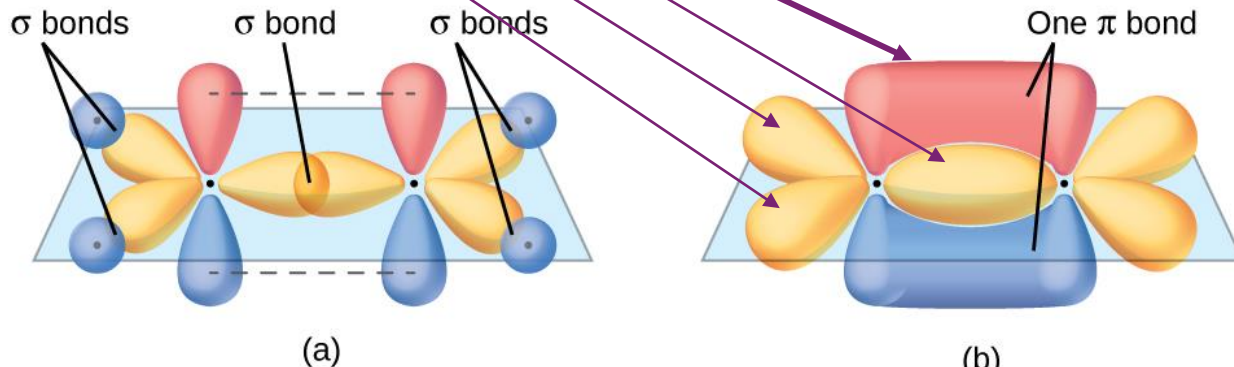
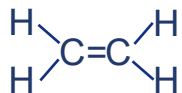
Graphic: Chemistry LibreTexts

Let's Talk Chemistry/Physics

Hybridisation

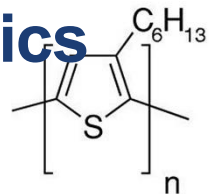


Ethene



Graphic: Chemistry LibreTexts

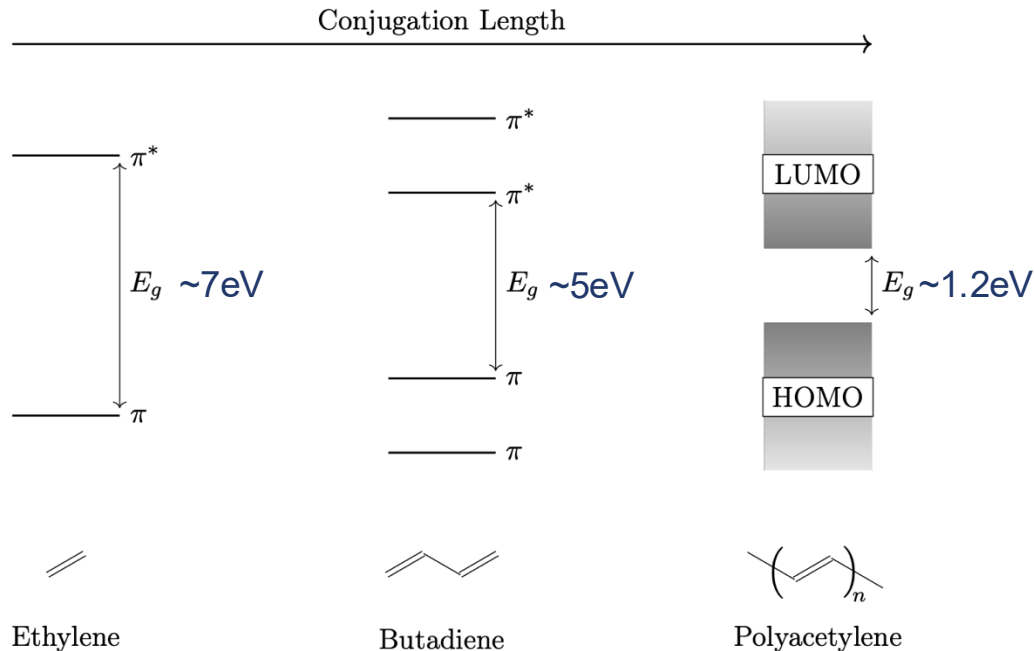
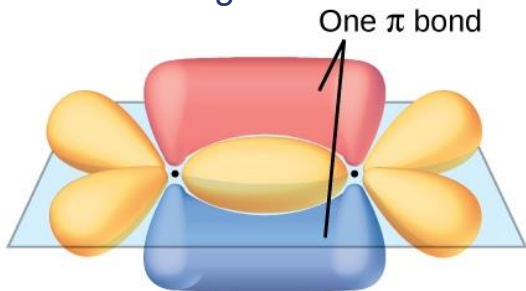
Let's Talk Talk Chemistry/Physics



Semiconductor

Conjugation

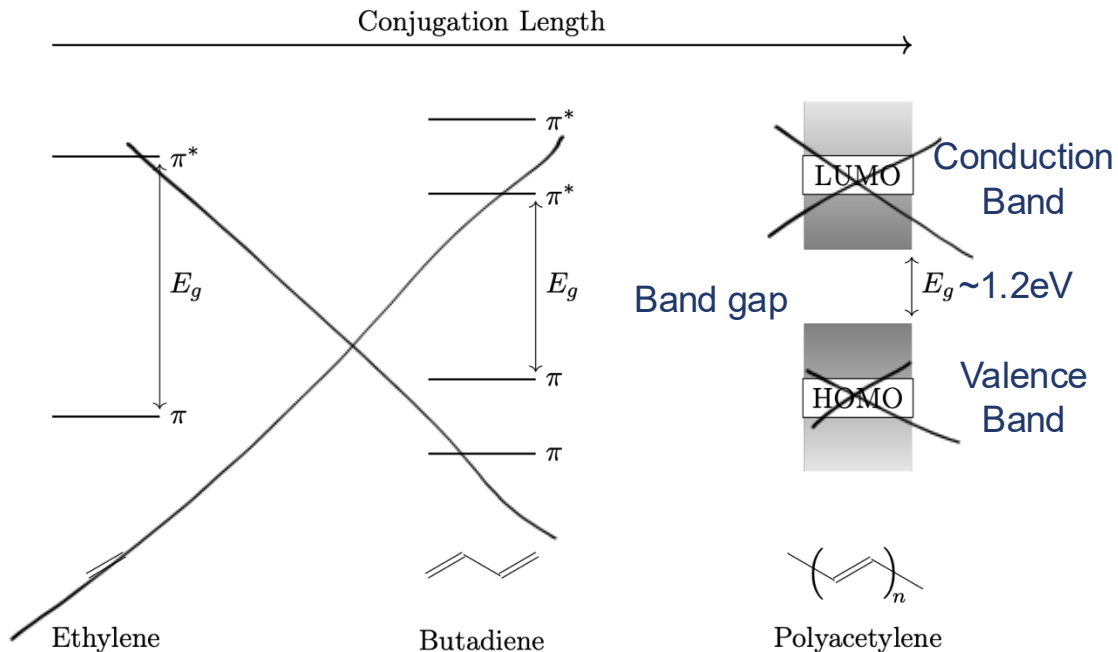
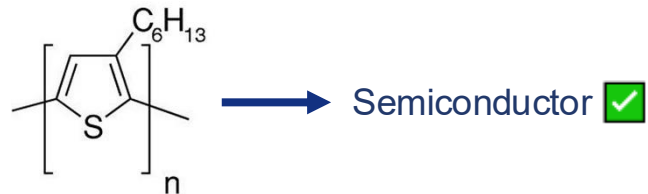
- π bond overlap over multiple sp^2 bonds is conjugation. Single-double alternating carbon bond.



This helps

Conjugation

If you are feeling like a game of spot the difference here.

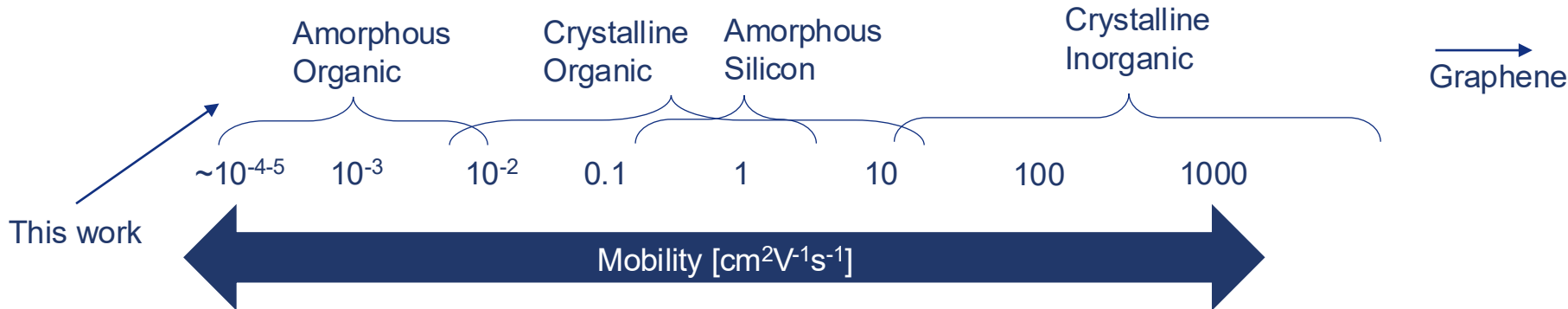


A Comparison to OI' Reliable

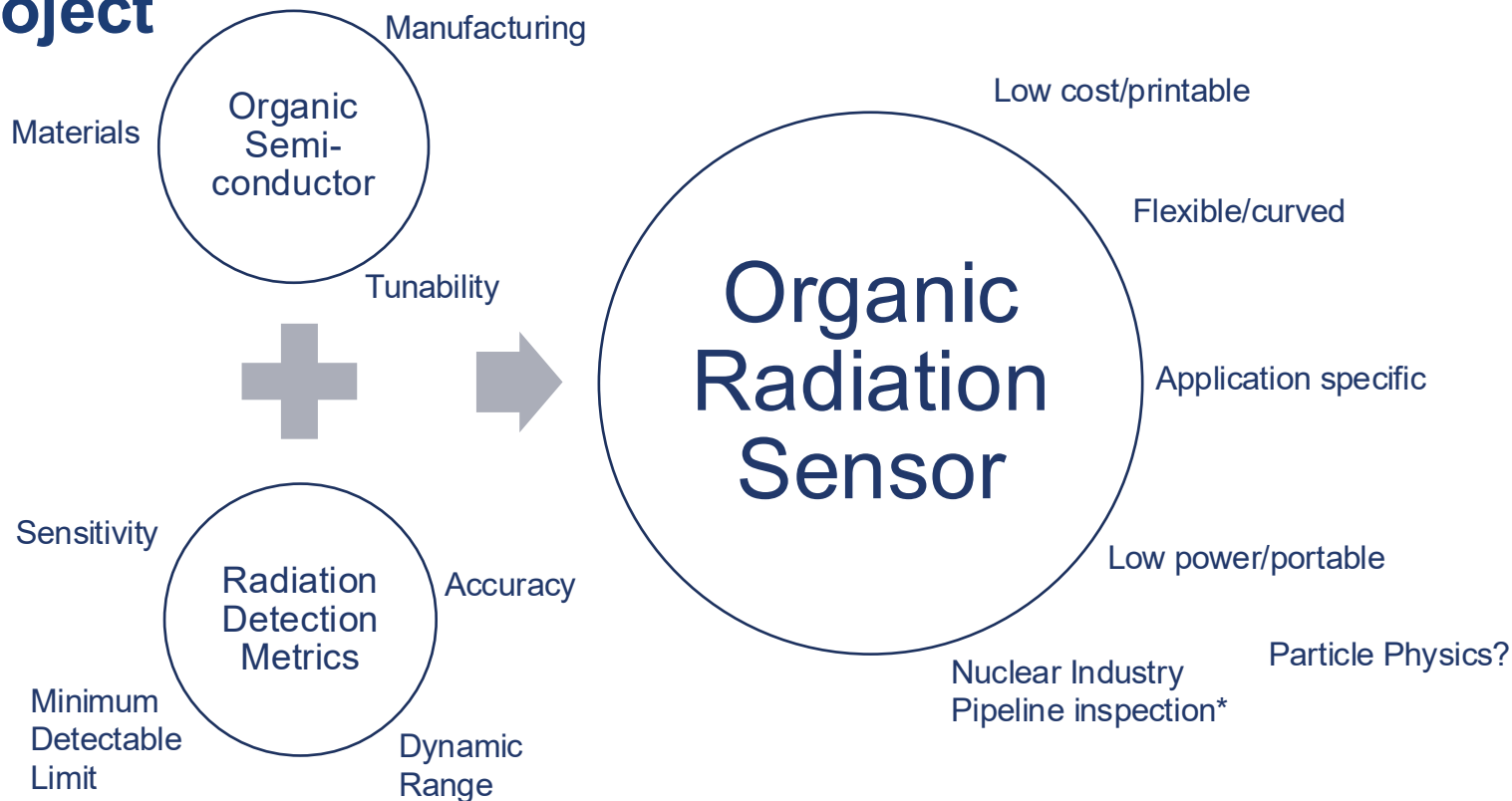
- Key differences
 - The range of processing techniques
 - Chemical vapour deposition no more.
 - Solution processed techniques are available
 - Printing
 - Physical vapour deposition.
 - Wider range of materials
 - Challenging, but sometimes helpful.

In Short:

- Low-cost electronics
- Tailor made (printed)
- But generally slower.



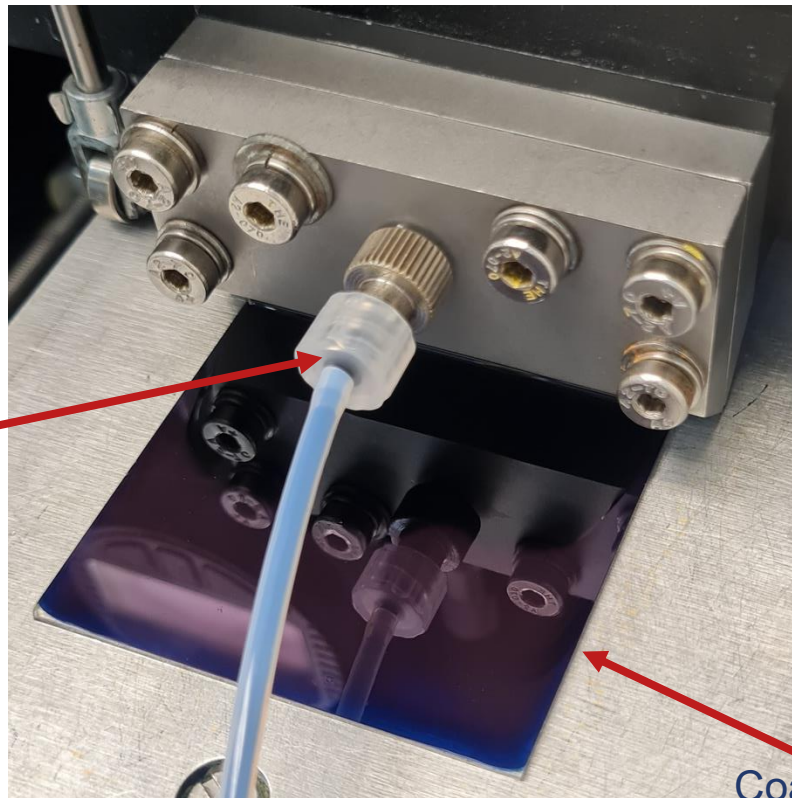
The Project



Manufacturing

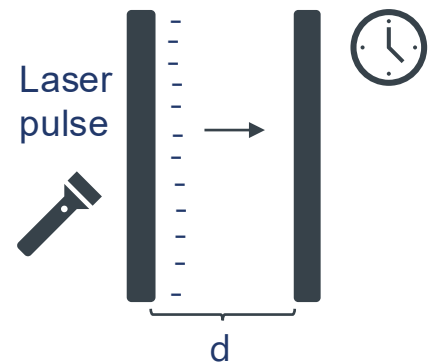
Printing of 30 μ m polymer films on glass substrates.

Polymer in solution



Coating output.

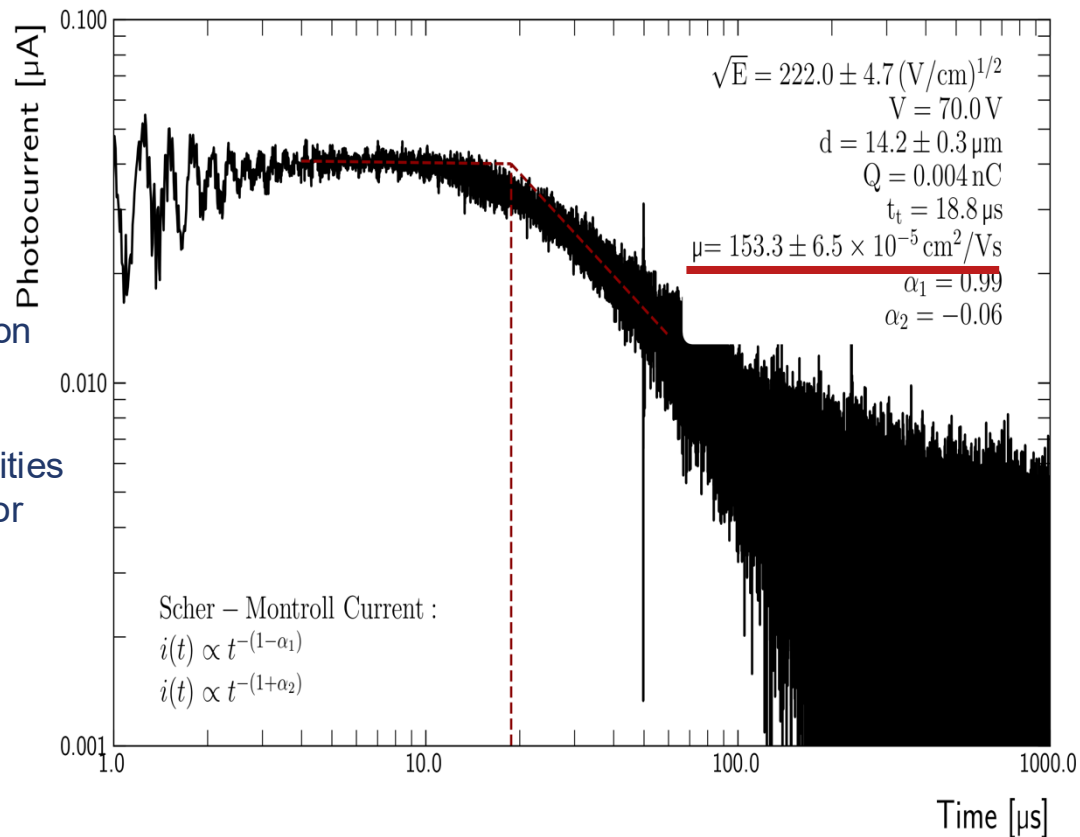
Carrier Mobility



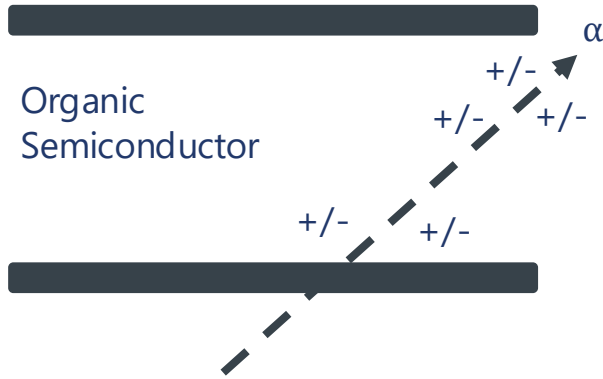
Unlike silicon radiation sensors

Charge carrier mobilities are under reported for organic materials.

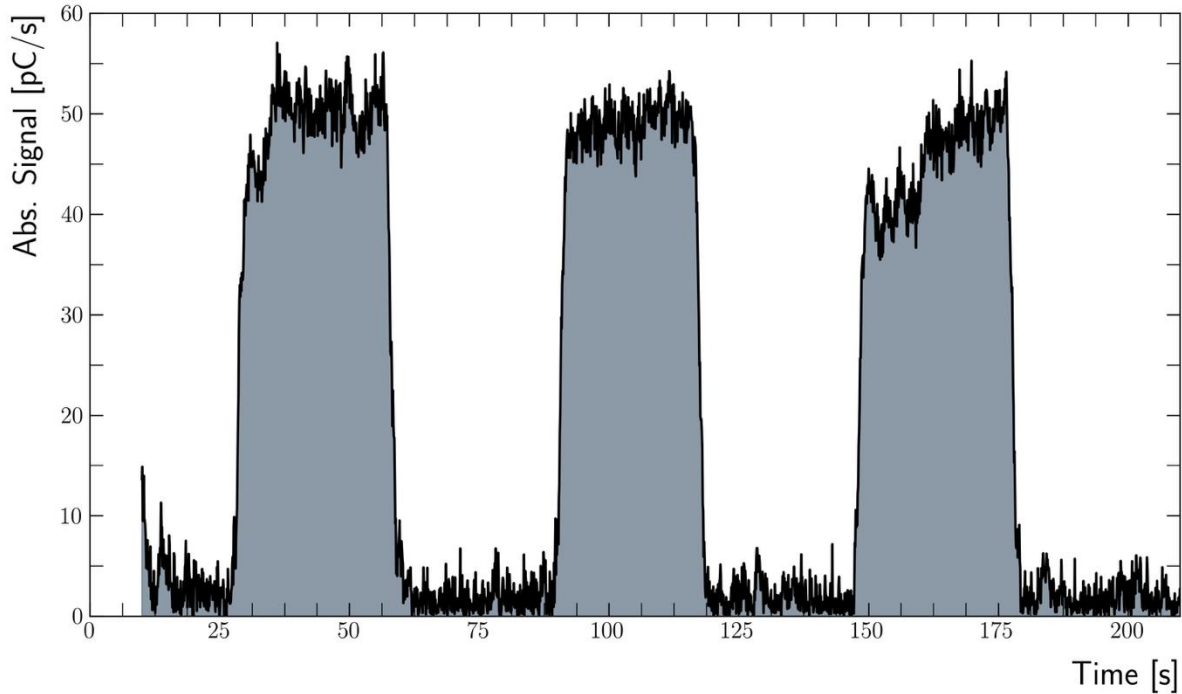
BYOM



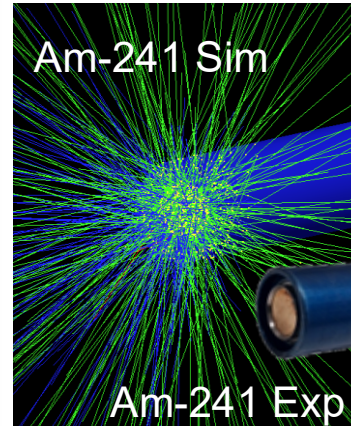
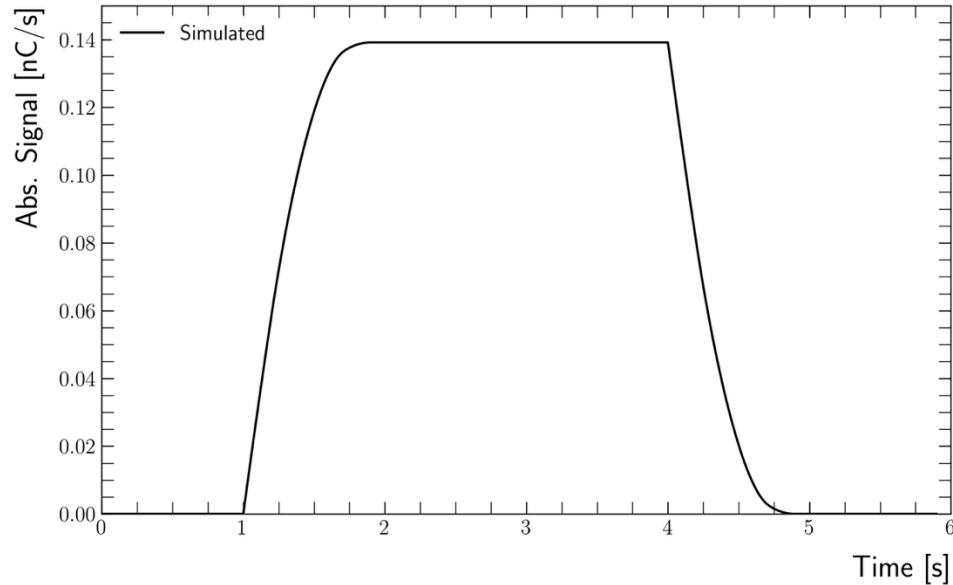
Detecting Radiation



Parallel plate capacitor geometry, kept simple.

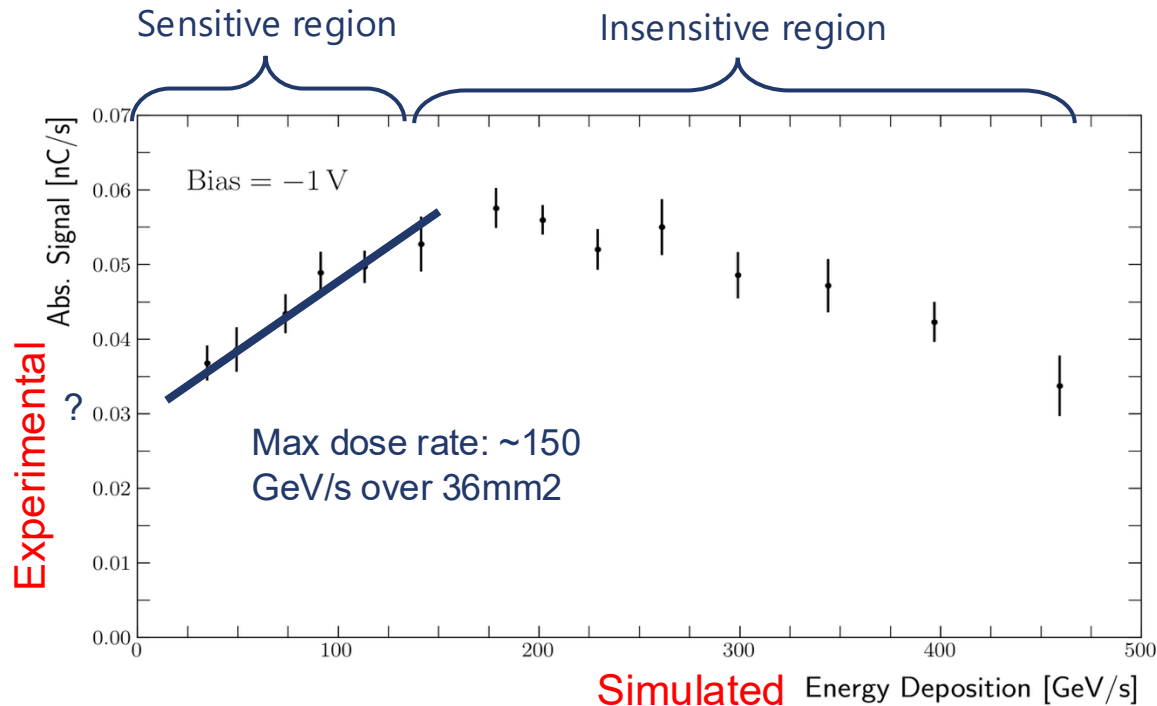


Detecting Radiation II



- Geometry + GEANT4 Simulation
- Reconstruct an 'expected' signal size.
- Steady-state current*.

Detecting Radiation III



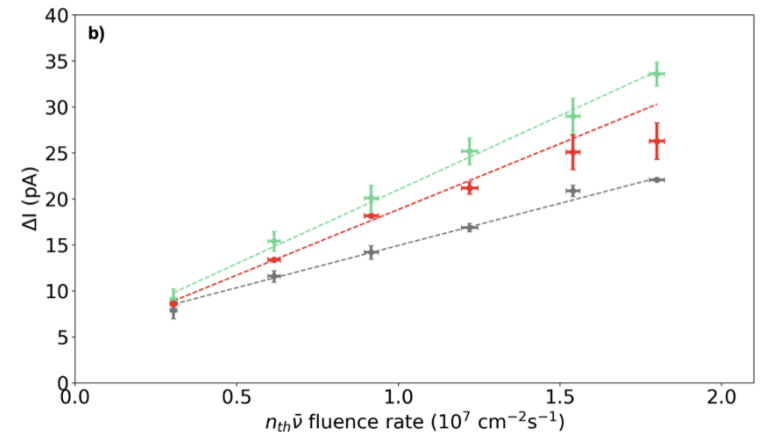
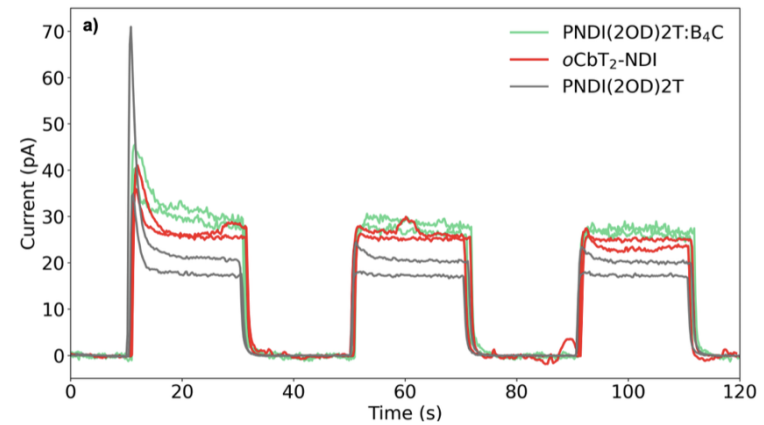
- An upper limit.
 - Space charge screening.
 - Insensitive
- Minimum limit
 - Poorly defined
 - Likely due to unrealistic geometry assumptions in the simulation

Future Plans

- Relax some assumptions on the detector geometry.
 - Parallel plate capacitor → true representation.
- Switch to Kapton substrates with electrodes prepatterned.
 - Flexibility/curvature
- What about radiation damage?
 - Interesting with an exotic material like this.
 - Sensor lifetime
- Field testing with a prototype.

What about the Particles?

- Can organic semiconductors be used in particle physics applications?
 - Maybe.
- Recent work has shown fast and thermal neutron detection.
- Neutron background event monitoring.
 - Dark matter exploration?



Horner *et al.* 2025 Direct Neutron Detectors based on Carborane Containing Conjugated Polymers, arXiv.



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